PB86-218435

Indoor Air Sampling and Mutagenicity Studies Related to Emissions from Unvented Coal Combustion

(U.S.) Health Effects Research Lab.
Research Triangle Park, NC

Jul 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-218435

EPA/600/D-86/141
July 1986

Indoor Air Sampling and Mutagenicity Studies Related to Emissions from Unvented Coal Combustion

Judy L. Mumford , D. Bruce Harris, and Katherine Williams
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Jane C. Chuang and Marcus Cooke
Battelle
505 King Street
Columbus, Ohio 43201

Health Effects Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/D-86/141		

4. TITLE AND SUBTITLE
INDOOR AIR SAMPLING AND MUTAGENICITY STUDIES RELATED TO EMISSIONS FROM UNVENTED COAL COMBUSTION

5. REPORT DATE
July 1986

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
J.L. Mumford[1], D.B. Harris[2], K. Williams[1], J.C. Chuang[3] and M. Cooke[3]

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
[1]HERL/RTP, NC 27711 [2]AEERL/RTP, NC 27711
[3]Battelle, 505 King St. Columbus, OH 43201

10. PROGRAM ELEMENT NO.
ANNA1E

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
EPA 600/11

15. SUPPLEMENTARY NOTES

16. ABSTRACT The purpose of this study is to develop sampling strategies and bioassay methods for indoor air in homes. The work reported here was conducted to prepare for a joint U.S.-China field study in Xuan Wei County, Yunnan Province, southern China, where the residents traditionally burn coal or wood for domestic cooking and heating without flue ventilation. These residents are exposed daily to high levels of combustion smoke and have unusually high lung cancer mortality rates, the women's rate the highest in China, and the men's rate among the highest. This paper reports the chemical and biological characterization of coal emissions from a simulated combustion laboratory. A medium-volume sampler (flow rate 0.11 m^3/min) with a PM_{10} size selective inlet, a filter, and an XAD-2 module was developed to collect the particulate matter and semivolatile organics. A high-volume particulate sampler with a PM_{10} size selective inlet was used for comparison with the medium-volume sampler. The percent organic extractable and polycyclic aromatic hydrocarbon (PAH) content of the filter and XAD-2, as well as the distribution of the organic matter, where determined. The mutagenicity of the filter and XAD-2 samples was determined by the Ames Salmonella mutagenesis assay. Most PAH compounds collected in the XAD-2 resin were equal to or smaller than 4-ring compounds and had much lower mutagenic activity than the filter sample. The filter samples contained a wide range of compounds, including 3- to 7-ring PAHs, and showed much higher mutagenic activity than XAD-2 samples. The coal combustion emitted both direct and indirect mutagens, most of which are frameshift mutagens.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	15
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ACKNOWLEDGMENTS

The authors wish to thank Mr. Leon Beddingfield of the U.S. Environmental Protection Agency for his technical assistance in sampling; Dr. Arthur Eckels of North Carolina Central University for his technical advice and encouragement; and the graduate students and the other faculty members at North Carolina Central University for their support of this project, including providing the combustion facility and assistance in sampling for this study.

ABSTRACT

INDOOR AIR SAMPLING AND MUTAGENICITY STUDIES RELATED TO EMISSIONS FROM UNVENTED COAL COMBUSTION, J.L. Mumford, D.B. Harris, and K. Williams, U.S. EPA, Research Triangle Park, NC 27711, and J.C. Chuang and M. Cooke, Battelle, Columbus, OH 43201.

The purpose of this study was to develop sampling strategies and bioassay methods for indoor air in homes. The work reported here was conducted to prepare for a joint U.S.–China field study in Xuan Wei County, Yunnan Province, southern China, where the residents traditionally burn coal or wood for domestic cooking and heating without flue ventilation. These residents are exposed daily to high levels of combustion smoke and have unusually high lung cancer mortality rates: the women's rate the highest in China, and the men's rate among the highest. This paper reports the chemical and biological characterization of coal emissions from a simulated combustion laboratory. A medium-volume sampler (flow rate 0.11 m^3/min) with a PM_{10} size selective inlet, a filter, and an XAD-2 module was developed to collect the particulate matter and semivolatile organics. A high-volume particulate sampler (flow rate 1.1 m^3/min) with a PM_{10} size selective inlet was used for comparison with the medium-volume sampler. The percent organic extractable and polycyclic aromatic hydrocarbon (PAH) content of the filter and XAD-2, as well as the distribution of the organic matter, were determined. The mutagenicity of the filter and XAD-2 samples was determined by the Ames *Salmonella* mutagenesis assay. Most PAH compounds collected in the XAD-2 resin were equal to or smaller than 4-ring compounds and had much lower mutagenic activity than the filter sample. The filter samples contained a wide range of compounds, including 3- to 7-ring PAHs, and showed much higher mutagenic activity than XAD-2 samples. The coal combustion emitted both direct- and indirect-acting mutagens, most of which were frameshift mutagens.

INTRODUCTION

Under a formal U.S.–China agreement,[1] the U.S. Environmental Protection Agency (EPA) is conducting a collaborative research program with the People's Republic of China to study the causes of unusually high lung cancer rates of the residents in a rural county, Xuan Wei, located in southern China. In this county, women's lung cancer mortality rates are the highest in China, and the men's rates are among the highest.[2,3] The epidemiologic background information suggests that the highly elevated lung cancer rate is not related to cigarette smoking or occupational exposure but is instead related to the residents' lifetime exposure to heavy smoke from the domestic use of smoky coal under unvented conditions. The U.S. side agreed to develop a sampling strategy to collect indoor air particles and semivolatile organics for chemical analyses and biological assays. Although initial intentions were to use the high-volume sampler (hi-vol) modified to collect semivolatile organic as well as particulate matter, early simulation tests showed the extremely high concentrations of particulate matter quickly overloaded the hi-vol. Thus, the only way to increase the sampling time for the collection of sufficient semivolatile matter was to change filters every few minutes. This intermittent sampling could severely compromise the organic samplers by possible contamination during idle periods.

This paper describes the development of a new medium-volume sampler (med-vol) to be used in Xuan Wei homes for indoor air sampling of particulate and semivolatile matter, and compares the testing results with those of the hi-vol, including particulate concentration, percent extractable organic matter, and mutagenicity of the particles collected. The distribution of the organics and the mutagenicity of the particulate and the semivolatile phase of the med-vol sampling were also determined.

METHODS

Coal Type and Simulated Combustion Facility

Tennessee bituminous coal was burned in an unvented shed (about 8 m^3) at North Carolina Central University, Durham, North Carolina. This coal, which contains 56.7% fixed carbon, 40.9% volatile organic matter, 0.7% sulfur, 2.4% ash, and 34.4 MJ/kg (14,781 Btu/lb) of heating value, is comparable to the Xuan Wei smoky coal in volatile matter and sulfur content and heating value. A round metal grill (50 cm in diameter, 15 cm above the floor) filled with a cast refractory was used as a burner to simulate open-pit burning on the floor of the Xuan Wei homes. The door of the shed was opened during sampling.

Development of a Med-Vol Particulate and Semivolatile Organic Sampling System

Concept Development. The EPA Air and Energy Engineering Research Laboratory at Research Triangle Park, North Carolina, has been monitoring industrial processes for years with a sampling system called the Source Assessment Sampling System (SASS), which collects particulate and semivolatile organic matter.[4] It was believed that this system or a derivative of it could be used for the U.S.–China program. The SASS consists of a heated sampling probe, which transports the gas effluents to a heated oven. Within that oven, three cyclones are connected in series to separate particles into >10 μm, 10- to 3-μm, and 3- to 1-μm fractions. Particles smaller than 1 μm are collected on a 142-mm filter also contained in the oven. From the oven, the sample goes to an organic collection module, where XAD-2 resin is used to adsorb semivolatile organic material. This module is followed by an impinger train, where water vapor and other condensable material are removed.

The sampling system used to test this concept consisted of the SASS cyclones, filter, and the adsorbent cartridge. All of these components were operated at ambient temperature. Control and pumping were achieved with the standard SASS component. The pumping capacity of the SASS system was the key to improving the sampling performance for this program; in addition, it enabled the collection of organic matter from the entire air stream rather than only a side stream.

Prototype Test. The SASS system was positioned next to the hi-vol to compare the performance of the two systems. The nozzle of the SASS was placed 15 cm away from the entrance of the hi-vol. The hi-vol was set to run at the standard flow rate of 1.1 m^3/min and the SASS was set for 0.11 m^3/min, its standard flow rate. After the fire was started, both samplers were turned on. The SASS sampled continuously for 45 min while the hi-vol required 20 filter changes. The test was terminated when the vacuum of the SASS pump inlet reached 25 cm Hg.

The test results indicated that very little material was separated in the cyclones (only 0.2% of the particulate matter was not found on the filter), and most of that was composed of long chain-like structures collected in the first (>10 μm) cyclone. A similar small amount of material was found in the hi-vol PM_{10} head (>10 μm).

Field Configuration. Although the SASS has a demonstrated desirability for certain applications, it was designed for stack sampling, and many of its features were not needed for ambient work. Thus, a med-vol sampler (Sierra-Andersen Series 254 by Sierra-Andersen, Atlanta, GA[5]), which has a pumping system similar to that of the SASS and also has a PM_{10} size selective inlet (SSI, with impaction chamber to retain particles larger than 10 μm), was merged with the SASS to provide the field system to be used in the U.S.–China project. The PM_{10} head from the ambient system was joined to the filter, organic adsorber cartridge, and pumping and control system from the SASS to form the medium-volume indoor air sampler (see Figure 1). This system was field-tested and found to perform similarly to the prototype, allowing sampling times of 30 min or more.

Application of Med-Vol and Comparison with Hi-Vol

Sample Collection. The coal fire was initiated with the ignition of kindling wood for each test run, and the coal (about 2 kg) was added subsequently. Sampling began when the wood was completely burned (about 30 min). The med-vol, containing a PM_{10} SSI, a filter (142 mm in diameter), and an XAD-2 (130 g, precleaned[4]) cartridge, as described previously, was used to collect the <10-μm particulate matter and semivolatile organics (bp 100-300°C) at 0.11 m^3/min. A hi-vol equipped with a PM_{10} inlet and a filter (20 cm by 25 cm) was used to collect <10-μm particles at 1.1 m^3/min and was compared with the med-vol. Glass fiber filters were used for both samplers. The distance between the hi-vol and the fire was set at 3.7 m for Run 8·12 and 0.9 m for Run 8·16 to determine any difference due to the location of the sampler. The med-vol was also located 0.9 m from the fire. The filter of the hi-vol was changed when the pressure across the flow orifice dropped to 9 cm H_2O for both runs. Frequent changes of the filter were required to maintain the constant flow rate. Total hi-vol sampling time was 138 min for Run 8·12 and 100 min for Run 8·16. For the med-vol, the total sampling time was 36 min with no filter change, with vacuum pressure of 25 cm Hg at the end of the sampling.

Analysis of Total Chromatographable Organics, Gravimetric Organics, and Polycyclic Aromatic Hydrocarbons. Organic material was removed from the filters and the XAD-2 resin by Soxhlet extraction with dichloromethane (DCM) for 16 h. Selected filters were also extracted with benzene after DCM extraction to determine if benzene removed additional organic matter. Aliquots of the extracts were analyzed for total chromatographable organics (TCO) by gas chromatography (GC) as described previously.[4] Separate aliquots of the concentrated extracts were dried for determination

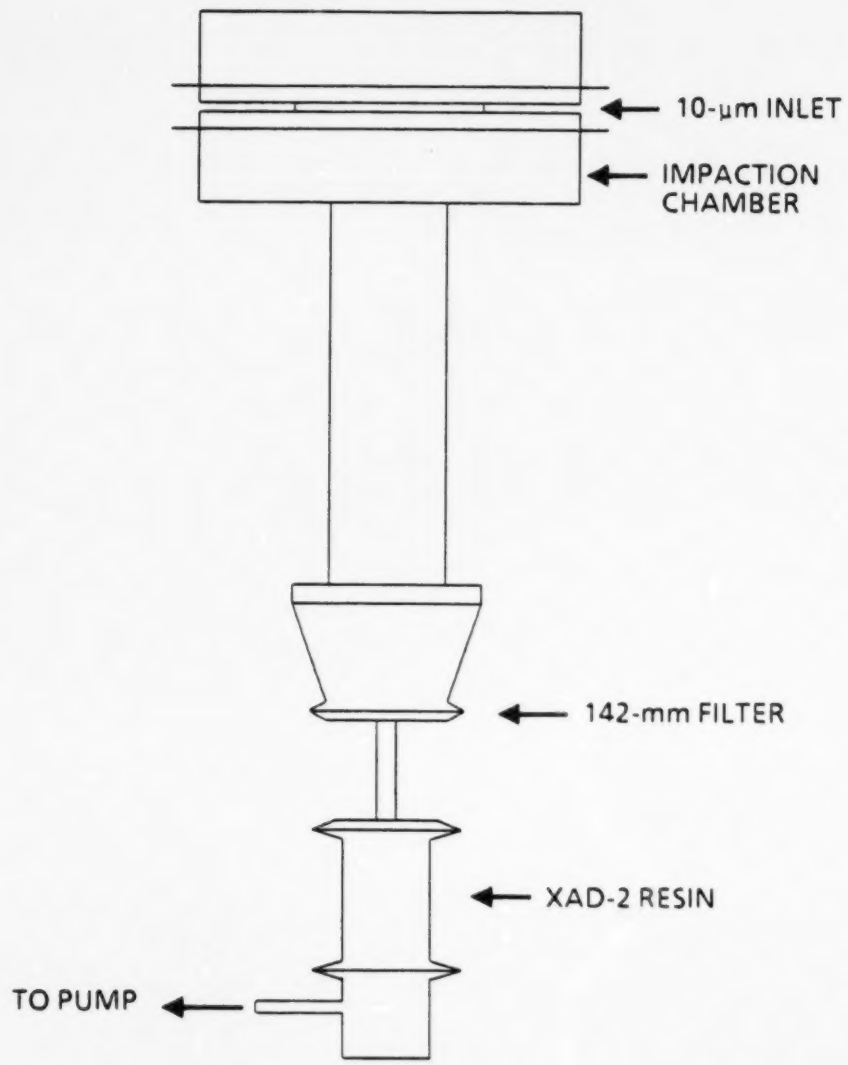

Figure 1. Medium-volume indoor air sampler.

of residue weight, which was used to calculate the percentage of the gravimetric (GRAV) organic mass that could be extracted. The extracts of the med-vol filter and the XAD sample were also analyzed for polycyclic aromatic hydrocarbon (PAH) determination using a Finnigan 4500 quadrupole mass spectrometer (MS) equipped with a GC and an INCOS 2300 data system. A fused-silica capillary GC column and on-column injection (45°C) with positive chemical ionization at 150 eV were employed. The protonate molecular ion of each compound of interest was monitored in the multiple ion detection mode.[6,7]

Ames Salmonella/Microsome Mutagenicity Assay. The DCM extracts of the samples were solvent exchanged to dimethyl sulfoxide and were bioassayed for mutagenicity using the standard *Salmonella typhimurium* plate incorporation assay[8] with minor modifications[9]: the standard minimal histidine was added to the plating media, instead of the soft agar overlay, and the plates were incubated for 72 h. The tester strains were obtained from Dr. Bruce Ames. For metabolic activation, a 9000-g supernatant (S9) of a liver homogenate was prepared using Aroclor-1254-induced male rats (Charles River, CD-1).[8] A minimum of five doses in triplicate was tested for each sample. A sample was considered mutagenic if a dose-response relationship was observed. In order to make a comparison with the med-vol filter sample, only the hi-vol filter samples (Run 8·12, Filters No. 1-5, and Run 8·16, Filters No. 1-6) collected during the initial 30 min were pooled and bioassayed.

RESULTS

Air Particulate Concentrations

High concentrations of the air particles (<10 μm) from the unvented coal combustion were found. Table I lists particulate concentrations during the initial 36 min (or less) of the sample collection. The hi-vol data show that the indoor particulate concentrations varied according to the distance of the sampler from the fire. When the sampler was closer to the fire, a higher particulate concentration was observed. When the distance from the fire was identical, both hi-vol and med-vol sampling resulted in similar particulate concentrations. The particulate emission rate for hi-vol Run 8·12 was estimated to be 8.2 g/kg coal.

Extractable Organic Mass and PAH Analysis

Table II shows the results of TCO and GRAV analysis of the filter and the XAD-2 samples. TCO was found only in the med-vol XAD-2 samples and not in any of the filter samples. Most of the GRAV or the higher molecular weight compounds were found in the filters. The ratio of the total extractable organic matter (TCO + GRAV) in the filter and the XAD-2 sample of the med-vol was 85:15. The percent of the extractable organic matter in the hi-vol filter samples varied according to the stage of combustion. The percentage of organic matter increased (from 50% to 90%) as combustion continued. Subsequent extraction by benzene resulted in a low percent (0.5-1.1%) of additional mass.

The results of the PAH analysis for the filter and the XAD-2 samples of the med-vol are shown in Table III. In the XAD-2 sample, only PAH compounds with up to four aromatic rings were observed. PAH compounds containing more than four rings were found in the filter sample.

Mutagenicity

The *Salmonella* mutagenicity assay results show that the mutagens of the air particles collected by the hi-vol were mainly frameshift mutagens, being positive in strains TA98, TA100, TA1537, and TA1538 with and without metabolic activation (data not shown). These samples were

TABLE I. Indoor air particulate (< 10 μm) concentrations from open-fire, unvented coal combustion.

Run	Distance from fire (m)	Particulate concentration[a] (mg/m^3)
hi-vol 8·12	3.7	22.1
hi-vol 8·16	0.9	38.3
med-vol 9·20	0.9	39.0

[a] Calculation was based on the initial 30 min of sampling for hi-vol Run 8.12 and initial 28 min for hi-vol Run 8.16 and initial 36 min for med-vol Run 9.20.

TABLE II. TCO and GRAV analysis for indoor air particles (<10μm) and semivolatiles from open-fire, unvented coal combustion.

Test Run/Sample	Filter/ XAD-2 No.	Collection Time (min)	Particulate Weight (g)	TCO (mg)	GRAV (mg)	Total Extractable Organic Matter[a] (mg)	Total Extractable Organic Matter (%)
hi-vol 8·12 filter	1	6	0.2284	0	120.8	120.8	52.9
hi-vol 8·12 filter	2	6	0.1574	0	78.4	78.4	49.8
hi-vol 8·12 filter	3	5	0.1099	0	39.5	39.5	35.9
hi-vol 8·12 filter	4	6	0.1189	0	51.2	51.2	43.1
hi-vol 8·12 filter	5	7	0.1145	0	44.7	44.7	39.0
hi-vol 8·12 filter	6	12	0.1902	0	128.2	128.2	67.4
hi-vol 8·12 filter	7	12	0.2257	0	161.1	161.1	71.4
hi-vol 8·12 filter	8	13	0.2221	0	169.6	169.6	76.4
hi-vol 8·12 filter	9	31	0.4586	0	375.6	375.6	81.9
hi-vol 8·12 filter	9[b]	—	—	0	5.2	5.2	1.1
hi-vol 8·12 filter	10	40	0.1071	0	97.2	97.2	90.7
hi-vol 8·16 filter	1,2,3	7	0.4503	0	231.2	231.2	51.3
hi-vol 8·16 filter	1,2,3[b]	—	—	0	2.1	2.1	0.5
hi-vol 8·16 filter	4,5,6	21	0.7300	0	551.2	551.2	75.5
hi-vol 8·16 filter	7,8,9	15	0.4323	0	225.1	225.1	52.1
hi-vol 8·16 filter	10,11,12	32	0.5391	0	486.9	486.9	90.3
hi-vol 8·16 filter	13,14	25	0.4589	0	429.0	429.0	93.5
med-vol 9·20 filter	1	36	0.1591	0	82.1	82.1 (85.1%)	51.6
med-vol 9·20 XAD-2	1	36	--	3.4	11.0	14.4 (14.9%)	--

[a] Total extractable organic matter = TCO + GRAV
[b] Benzene extraction was performed after dichloromethane extraction

TABLE III. PAH concentrations of indoor air particles (<10 μm) and semivolatiles collected by med-vol from open-fire, unvented coal combustion.

Compound	9-20-XAD (μg/m³)	9-20-Filter (μg/m³)
Pyrene	4.5	52.3
Fluoranthene	7.0	60.3
Benzo[c]phenanthrene	BDL[a]	6.3
Benzo[a]anthracene[b]	BDL	19.4
Chrysene	BDL	18.0
Cyclopenta[c,d]pyrene[c]	BDL	16.3
Benzofluoranthenes[b]	BDL	23.4
Benzo[e]pyrene	BDL	8.0
Benzo[a]pyrene[b]	BDL	10.3
Perylene	BDL	2.3
Indeno[1,2,3-cd]pyrene[b]	BDL	6.3
Benzo[g,h,i]perylene	BDL	7.1
Dibenzo[a,c]anthracene[c]	BDL	2.3
Dibenzo[a,h]anthracene[b]	BDL	2.3
Dibenzo[a,e]pyrene[b]	BDL	4.0
Dibenzo[a,i]pyrene[b]	BDL	1.4
Dibenzo[a,l]pyrene[b]	BDL	2.3
Coronene	BDL	2.3

[a] BDL = below detection limit.
[b] Compound shows sufficient evidence of carcinogenicity in experimental animals.[13]
[c] Compound is active in short-term bioassays.[10]

negative in TA1535, with and without metabolic activation. Strain TA98 was selected to compare the mutagenicity of the hi-vol and the med-vol samples (see Figure 2). With the exception of somewhat lower mutagenicity in hi-vol 8-12 without activation, all the filter samples (both hi-vol and med-vol samples) showed comparable mutagenicity, both with and without metabolic activation. For the med-vol samples, little mutagenicity was found in the XAD-2 sample; most of the mutagenic activity was found in the filter sample.

DISCUSSION

This study was conducted to develop sampling strategy and to chemically and toxicologically characterize the emissions from simulated indoor coal combustion prior to the field study to be conducted in Xuan Wei, China. A 0.11-m^3/min med-vol that includes a PM_{10} SSI, filter, and XAD-2 module was developed to collect the particulate matter (< 10 μm) and semivolatile organics. A hi-vol with a PM_{10} SSI was also compared to the med-vol. The indoor air particulate concentrations measured by the hi-vol and the med-vol were comparable. The med-vol was operated at one-tenth the flow rate of the hi-vol and collected samples for a longer period of time without a filter change, in marked contrast to the hi-vol, which could collect samples for only a few minutes before the filter had to be changed. Thus, the med-vol enables collection of semivolatile organics by XAD-2 without interruption.

Results of this study indicated that 15% (all in the form of TCO) of the total extractable organic mass was trapped in the XAD-2 and 85% (all in the form of GRAV) of the organic mass was retained in the filter. With lower molecular weight compounds, TCO was found only in the XAD-2. PAH analysis, which showed that XAD-2 samples contained compounds with four or fewer aromatic rings, confirmed this finding. Most of the PAH compounds containing more than four rings were detected in the filter sample.

The mutagenicity assays showed that the unvented, open-fire coal combustion emitted both direct and indirect-acting frameshift mutagens. Most of the mutagens were detected in the filter samples. The mutagenic activity detected in the organic extracts of the hi-vol and the med-vol filter samples was comparable. Little mutagenicity was found in the XAD-2 sample. The mutagenicity results are in agreement with the results of the PAH analysis, which indicated that most of the biologically active compounds (e.g., benzo[a]pyrene), usually containing more than four aromatic rings, were found in the filter sample and not in the XAD sample. It is known that combustion and distillation products of coal generate carcinogens, in particular, PAH compounds.[10] Occupational health studies have shown that exposure to coal tar and coal combustion products is related to cancers of lung, larynx, skin, scrotum, and bladder in gas workers, stokers, coke oven workers, and chimney sweeps.[11,12]

In comparison with the hi-vol, the med-vol has the following advantages for indoor air sampling: (1) enables the collection of semivolatile organics from the same air stream of the particulate sample without frequent filter changes, (2) decreases clean air effects because of its lower flow rate, (3) has enhanced portablity because it is lighter and less bulky, and (4) generates less noise. However, the med-vol does have the disadvantage of collecting smaller quantities of particulate matter on the filter because of its lower flow rate.

As a result of this study, the hi-vol sampler with a PM_{10} SSI was used in Xuan Wei to collect large quantities of indoor and outdoor air particles (< 10 μm) for detailed chemical characterization and bioassays. The newly developed med-vol was used in the collection of both particulate matter and semivolatile organics of air samples for Xuan Wei homes. In addition, this med-vol has also been used for both indoor and outdoor sampling in two other projects (integrated air cancer project and indoor kerosene heater project) sponsored by the U.S. Environmental Protection Agency.

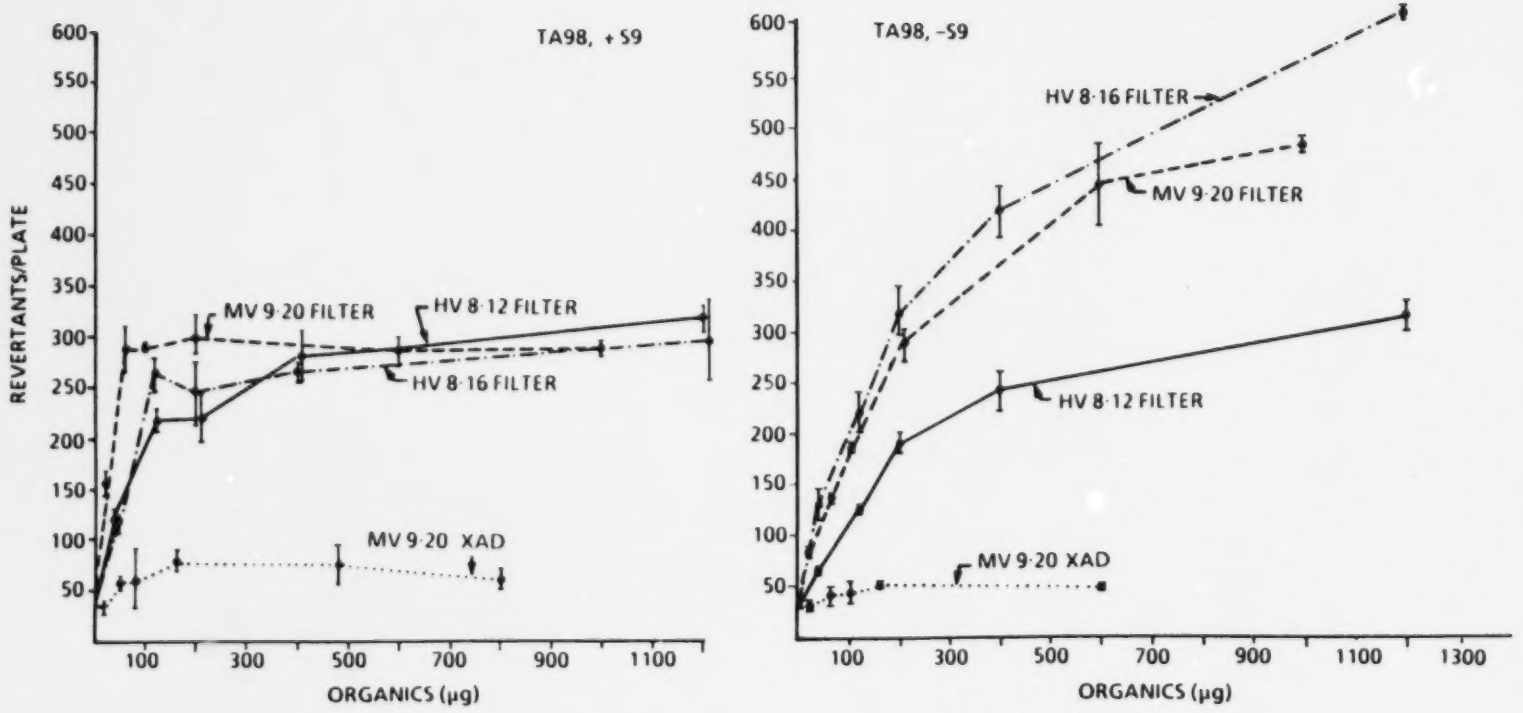

Figure 2. Mutagenicity of the organic extracts of the indoor air particles (< 10 µm) and semivolatiles from open-fire, unvented coal combustion in *Salmonella typhimurium* plate incorporation assay. Data shown are mean ± standard deviation. MV = medium-volume sampler; HV = high-volume sampler.

REFERENCES

1. *Protocol Between the United States Environmental Protection Agency and the Office of the Environmental Protection Leading Group of the State Council of the People's Republic of China for Scientific and Technical Cooperation in the Field of Environmental Protection.* Annex 1, Item II. 1980.

2. The Editoral Committee for the Atlas of Cancer Mortality in the People's Republic of China, Atlas of Cancer Mortality in the People's Republic of China, 1st ed., China Map Press, Shanghai, 1979.

3. Office of Tumor Preventive Research, Department of Public Health, the People's Republic of China, *Investigation and Research of Chinese Cancer Mortality Rates*, People's Public Health, Beijing, 1979, Chapter 7, pp. 148-174.

4. D.E. Lentzen, D.E. Wagoner, E.D. Estes and W.F. Gutknecht, *IERL-RTP Procedures Manual: Level 1 Environmental Assessment*, 2nd ed., EPA-600/7-78-201, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1978.

5. Sierra-Andersen, Inc., Bulletin No. SA-PM10-682, Sierra Andersen, Atlanta, GA.

6. M.G. Nishioka, B.A. Petersen and J. Lewtas, *Polynuclear Aromatic Hydrocarbons: Physical and Biological Chemistry*, M. Cooke, A.J. Dennis and G.L. Fisher, eds., Battelle Press, Columbus, OH, 1982, pp. 603-612.

7. B.A. Petersen, C.C. Chuang, T.L. Hayes and David A. Trayser. *Polynuclear Aromatic Hydrocarbons: Physical and Biological Chemistry*, M. Cooke, A.J. Dennis and G.L. Fisher, eds., Battelle Press, Columbus, OH, 1982, pp. 641-653.

8. B.W. Ames, J.M. McCann and E. Yamasaki, "Methods for detecting carcinogens and mutagens with the Salmonella/mammalian microsome mutagenicity test," *Mutat. Res.* **31**:347-364 (1975).

9. L.D. Claxton, "Mutagenic and carcinogenic potency of diesel and related environmental emissions: Salmonella bioassay," *Environ. Int.* **5**:389-391 (1981).

10. IARC (International Agency for Research on Cancer), *IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans*, Vol. 32: *Polynuclear Aromatic Compounds. Part 1. Chemical, Environmental, and Experimental Data*, International Agency for Research on Cancer, Lyon, 1983, pp. 95-447.

11. P. Cole and M.B. Goldman, *Persons at High Risk of Cancer*, J.F. Fraumeni, ed., Academic Press, New York, 1975, Chapter 11, pp. 167-184.

12. P. Pott, *Chirurgical Observations*, Hawes, Clarke, and Collins, London, 1775.